International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 14, No. 2, June 2023, pp. 1218~1229
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i2.pp1218-1229

Design of a multi-level inverter for solar power systems with a variable number of levels technique

Mohammed A. Qasim [1,2], Vladimir Ivanovich Velkin[1], Mustafa Fawzi Mohammed [3], Alaa Ahmad Sammour[4], Yang Du[1], Sajjad Abdul-Adheem Salih[1], Baseem Abdulkareem Aljashaami[1], Sharipov Parviz Gulmurodovich[1]

[1]Nuclear Power Plants and Renewable Energy Sources Department, Ural Federal University, Yekaterinburg, Russia
[2]Department of Projects and Engineering Services, Ministry of Health, Baghdad, Iraq
[3]Department of Business Information Technology, College of Business Informatics, University of Information Technology and Communications, Baghdad, Iraq
[4]Turbines and Engines Department, Ural Federal University, Yekaterinburg, Russia

Article Info

Article history:

Received Sep 26, 2022
Revised Feb 10, 2023
Accepted Feb 23, 2023

Keywords:

Harmonic
MATLAB/Simulink
Multilevel inverter
PV
Switch

ABSTRACT

Overall harmonic distortion and losses will grow during an energy conversion process, while power stability will be reduced. Multilevel inverter technologies have recently become very popular as low-cost alternatives for a variety of industrial purposes. The design's minimal benefits include reduced component losses, decreased switching and conduction losses, along with enhanced output voltage and current waveforms. Also, a reduction of the harmonic components of the current and output voltage of the inverter are the most important requirements in multilevel inverters. A seven-level inverter design is presented in this paper that is simulated using MATLAB/Simulink. The inverter converts the DC voltage from three photovoltaic (PV) systems into AC voltage at seven levels. During an outage of one of the PV systems, the inverter will make a switching reduction and supply the AC voltage as a five-level inverter. The inverter's total harmonic distortion (THD) when it performs as a five-level or seven-level inverter is 4.19% or 1.13% respectively. The modulation technique used is phase disposition via six carriers and a single reference signal at the fundamental frequency.

Corresponding Author:

Mohammed A. Qasim
Nuclear Power Plants and Renewable Energy Sources Department, Ural Federal University
Yekaterinburg 620002, Rusia
Email: mohammed.a.k.qasim@gmail.com

1. INTRODUCTION

Since traditional energy sources are being rapidly depleted and their use has brought negative environmental consequences, renewable energy sources (RES) have become popular alternatives for energy generation [1]. The quantity of energy generated by renewable energy resources varies throughout the day and optimizing the supplied energy is crucial [2]. Solar radiation intensity affects the output of a photovoltaic array. Consequently, variations in this factor must be handled effectively by such systems. It is necessary to modulate the output system DC voltage and current to operate a PV system so that it can achieve its maximum power point (MPP) [3]. The most significant challenge that an RES may face is creation of electrical energy in the form of a DC power source that needs conversion devices to transform it into AC power.

Multilevel inverters (MLI) are normally employed at the DC output ports on an RES. This is done to transform DC electricity into AC power as well as to improve power quality and reliability [4]. Improved current and output voltage waveforms, reduced electro-magnetic interference (EMI), compact size, and decreased total harmonic distortion (THD) are advantages of MLIs [5]. The use of MLIs is an attractive approach to construct stand-alone inverters that operate at a few kilowatts [6]. Three major multilevel inverter topologies are utilized in commercial processes with distinct DC sources. These inverter types are diode clamped, flying capacitor and cascaded H-bridge. There is difficulty with capacitor voltage balancing in the flying capacitor and diode-clamped inverters, but this issue is resolved in cascaded H bridge inverters [7]. To determine the voltage levels for traditional multilevel inverters, the relation (2h+1) is used [8], where (h) is the number of bridges. This means that to produce seven voltage levels, 3 H-bridges are needed, requiring a total of twelve switches. Twelve switches and three DC sources are needed for conventional cascaded seven-level multilevel inverters. The fundamental disadvantage of conventional cascaded inverters is that when the number of levels increases, more semiconductor switches are required. Therefore, certain changes will be necessary to decrease the inverter size and turn it off [9]. MLI switches determine equipment cost, circuit size, and installation dependability, as well as control complexity. In classic MLIs, inverter size and cost increase with the output voltage level. The current study shows that MLIs with fewer switches can more inexpensively provide many output levels. An MLI with fewer the switches reduces switch voltage stress while simultaneously enhancing safety against over-voltage and dV/dt failure [10].

In work presented by Archana and Anupamma [11], a MLI supplied for renewable energy sources (wind and solar energy) was modeled in a stand-alone system using MATLAB/Simulink software, with varying wind speeds and sun irradiation. The major benefits of MLIs were identified in the research by Nouaiti *et al.* [12] who created a design with two parts. The first is a DC/DC boost converter powered by PV cells. It is divided into two stages, an amplification stage with switched capacitors and a standard boost chopper stage. The second section of the design is a five-level inverter with two carriers and one reference signal for PWM for switching devices. A 200 W prototype is designed, powered by PV panels, to supply an inductive load. The design is subjected to simulation and experimental testing. A T-type seven-level inverter was proposed by Mohammed *et al.* [13]. It was a seven-level MLI designed for renewable energy sources. Based on the modulation technique used, the number of levels can be changed according to variation of the modulation index value. Azeem *et al.* [14], introduced a single-phase seven-level packed u-cell (PUC) multilevel inverter was connected with a zeta converter for PV applications, using solar energy systems as power sources. In comparison to traditional systems, the developed system minimizes switching losses, THD, cost, and size while improving output waveforms. Redesigned MLIs are promising options for PV solar systems and other renewable energy systems [15]. Novel converters are employed to increase energy conversion in present energy systems. The characteristics of MLIs were summarized in work presented by Sathik *et al.* [16] to underline the importance of grid-connected and PV systems. The current study addresses MLI size, cost, lower THD, and high conversion efficiency. Considering the above benefits of using switch reduction technology, this work built and implemented a single-phase MLI based switch reduction technology employing three PV sources in a stand-alone system. This study uses a novel switching mechanism and pulse width modulation (PWM) to develop seven output voltage levels employing seven switches. Also, it is possible to easily shift from seven levels to five levels without changing the peak value of its output voltage. In this study, three PV-solar systems are offered as power sources and modeled using the MATLAB/Simulink tool. The three PV sources are (1/3 Vdc, 2/3 Vdc, and Vdc) to create seven voltage levels. This paper has been organized as follows: An introduction is presented followed by a system description which includes (system components configuration, PV system, boost converter, and multilevel inverter), simulation results, and conclusions.

2. SYSTEM DESCRIPTION

2.1. System component configuration

Three distinct PV solar systems connected using a DC-DC boost converter (1/3 Vdc, 2/3 Vdc, and Vdc) are recommended, as depicted in Figure 1. Voltage levels from the PV voltage to three voltage levels, 1/3 Vdc, 2/3 Vdc, and Vdc, are increased with a boost converter. Each PV system is connected in parallel to the main switch. PV-1 is connected to switch SP1, PV-2 is connected to switch SP2, and PV-3 is connected to SP3. The switches (S1 to S4) work alternately to produce seven voltage levels. This seven-level output voltage was generated by combining the DC sources (+Vdc to -Vdc). If one of the PV systems (PV-1 or PV-2) fails, the recommended circuit will function with two PV systems to generate five voltage levels. Otherwise, a seven-level voltage will be produced. An LC filter was designed in this study to improve the output voltage by reducing the harmonics and make the outputs (voltage and current) as purely sinusoidal as possible.

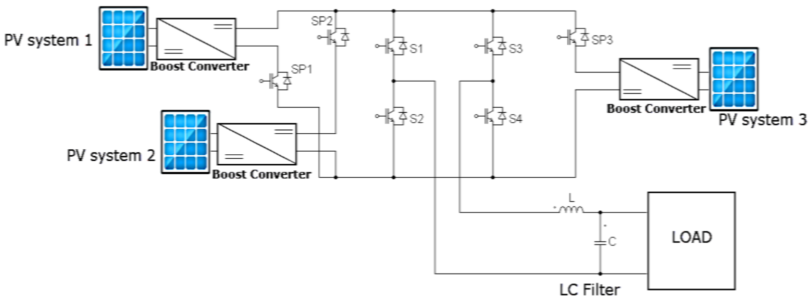


Figure 1. The proposed system configuration

2.2. PV system

Light is converted into power via photovoltaic cells arranged in arrays and panels. Whenever exposed to light, individual cells act as diodes, producing electron-hole pairs. Flows of electrons and holes in the electric material are created by the diode's n-p junction and they are forced out, due to the interface potential, into an external circuit. Thermal losses result from the parallel resistance of cells and leaked current at n-p junctions [17]. Weather, sky conditions, temperature, and the location of the sun all impact solar irradiation. Each of these factors introduces much fluctuation in the output voltage and current, leading to non-linear behavior. To counteract this, a step-up converter employs an MPP tracking (MPPT) approach to realize maximal power output [18].

PV cells are fabricated from p- and n-type semiconductor materials. In practice, PV cells are diodes. When they are exposed to light, the photovoltaic cells create a current. Generally, PV modules require many solar cells connected in parallel and series to achieve sufficient voltage and power [19]. A forward-biased parallel diode connected to a current source is represented in Figure 2 [20]. A PV-cell's load current is given as:

$$I = I_L - I_D - I_{SH} \tag{1}$$

$$I = I_L - I_0 * \left[\exp\left(\frac{q\,V_D}{nkT} - 1\right) - \frac{V_D}{R_{SH}}\right] \tag{2}$$

where I_L represents the photovoltaic current in amps, I_D is the diode current in amps, I_{SH} represents the shunt resistor current in amps, V_D is the diode voltage in volts, I_0 represents the reverse saturation current in amps, q is the electron charge, (1.6×10^{-19}) (C), and k represents the Boltzmann constant $(1.38\times10^{-23}$ J/K). A solar cell's power output is:

$$P_{PV} = V \times I \tag{3}$$

I depicts the solar cell output current in amps, V is the solar cell voltage in volts, and P_{PV} is the solar cell output power in Watts. Due to losses in the resistors, the voltage and current characteristics of the solar cell deviate from theoretical values. The maximum power generation of a PV solar system may be obtained using an MPPT approach to adjust the position of PV system panels. There are numerous control strategies that may be employed to acquire the greatest output power in solar systems. In the current study, we apply the perturb and observe (P&O) method. This technique measures a solar panel's output voltage and current. It then utilizes this data to determine if the DC-DC converter's duty cycle should be increased or reduced [21], [22]. When the operational point is to the right of the MPP, the P/V ratio is negative, and vice versa. When the P/V ratio is non-zero, the tracking system shifts the panel position until there are no changes in power or voltage. The PV system (I-V) and (P-V) characteristics appear in Figure 3. Figure 4 depicts the P&O algorithm as a flowchart [23].

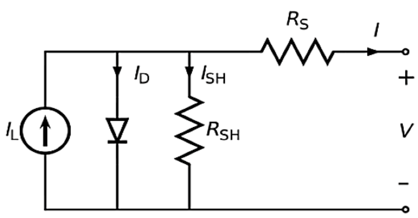


Figure 2. Circuit diagram of a PV-cell [20]

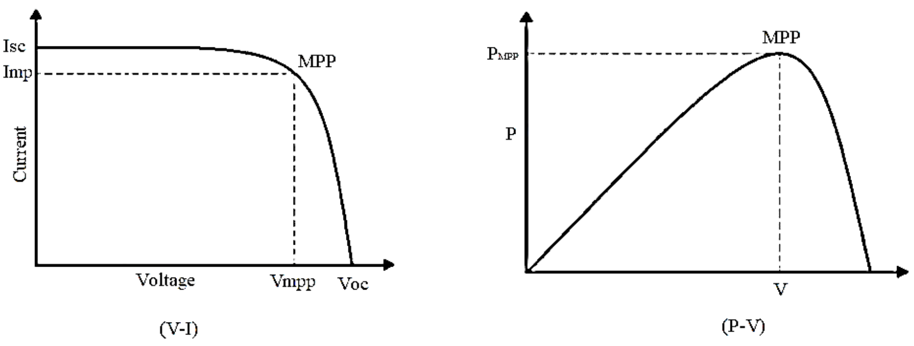


Figure 3. (V-I) and (P-V) solar cell characteristics in the current study [21]

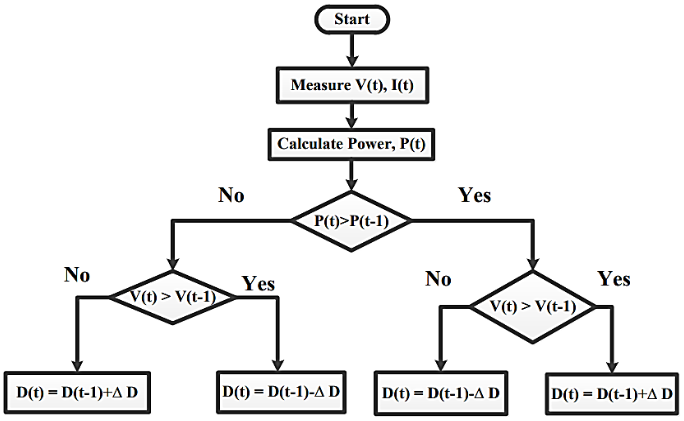


Figure 4. Flowchart depicting the P&O algorithm [23]

2.3. Boost converter

Step-up converters, also known as boost converters are widely employed to enhance the DC output voltage of PV solar systems and achieve the DC bus voltage. Boost converter system losses will be reduced when voltage is increased. Figure 5 shows circuit diagram of this device. In the on position, the diode forms an open circuit and inductor L charges the device. However, in the off position, the diode conducts, so that input and inductor voltages are output. Capacitor C reduces the ripple factor of the output waveform [24].

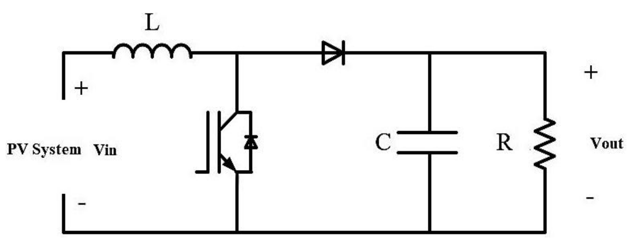


Figure 5. Circuit diagram of a DC-DC step-up or boost converter [25]

2.4. Multilevel inverter

Inverters convert direct current (DC) to alternating current (AC). They are commonly employed in domestic power applications including motors, UPS, and other devices. MLIs are becoming more common in high-power switching applications. Large switching frequencies reduce ripple in the output voltage or current waveform. This improves power quality. MLIs with a reduced number of switches have considerable problems in applications with high-frequency, high-power, and medium-voltage that are due to switching losses and device rating limits [26]–[28].

Pulse width modulation (PWM) is a very effective control algorithm for inverter internal voltage regulation. In these applications, pulse width refers to the breadth of an output pulse. This is determined as the conduction time of each switch. For bridge inverters, each switch conducts for the duration of its gate pulse.

Here, the output pulse width is precisely proportional to the pulse period [29]. A phase disposition approach is used to disperse numerous trapezoidal carriers. The phase disposition approach has the benefit of being simple to implement and having lower overall harmonic distortion. To obtain the signal of the switches, these carriers are compared to a sine waveform referenced as V_sine. The switching frequency of an inverter is that same of as the carrier frequency. The carrier frequency is focused on harmonic energy in this approach. A phase placement approach is used to disperse the many triangular carriers, and this technique is called phase disposition [30]–[33]. The output pulse width changes with the gate pulse duration, adjusting and controlling the voltage. PWM is classified as one of two types depending on the method of gate pulse duration adjustment. Figure 6 shows a multicarrier PWM that uses a reference sine wave to create a seven-level voltage.

In this study, logical design of a PWM controller is implemented. Figure 7 shows the proposed control based on PWM. Whenever the value of Ma is less than 0.33, there are only three values for the output voltage (+Vdc/3, 0, -Vdc/3). Output voltage is divided into five levels. Their modulation indices range from 0.33 to 0.67 (+2Vdc/3, +Vdc/3, 0, -Vdc/3, -2Vdc/3). With a modulation index of 0.67 to 1, a seven-level output voltage is formed (+Vdc, +2Vdc/3, +Vdc/3, 0, -Vdc/3, -2Vdc/3, -Vdc), as seen in Table 1.

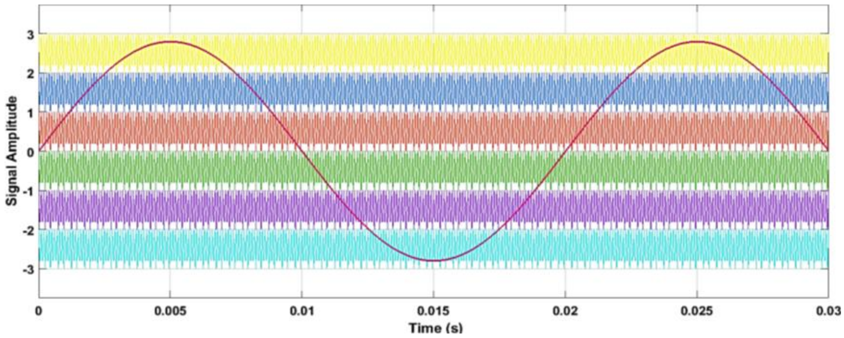


Figure 6. A multicarrier and base sinusoidal signal of the proposed PWM controller

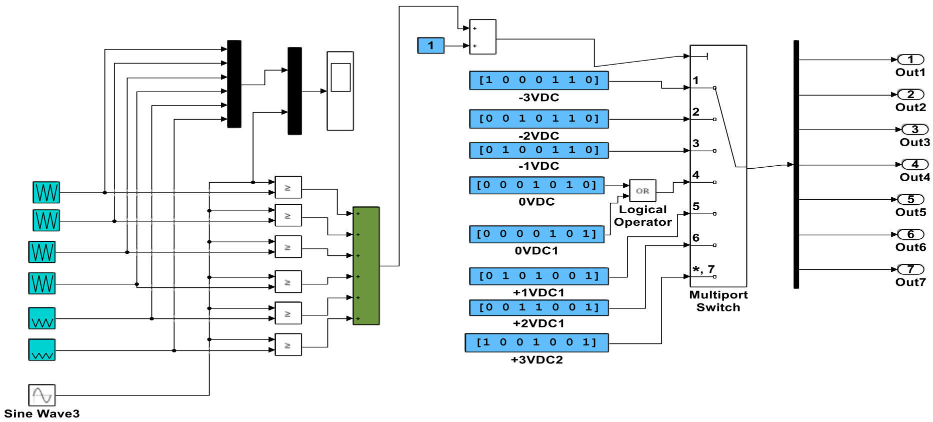


Figure 7. Control of switches with an MLI based on the PWM technique

Table 1. The proposed MLI with switching status and output voltage

Voltage Level	Sp3	Sp1	Sp2	S1	S2	S3	S4
Vdc	1	0	0	1	0	0	1
2/3 Vdc	0	0	1	1	0	0	1
1/3 Vdc	0	1	0	1	0	0	1
0	0	0	0	0	1	1	1
-1/3 Vdc	0	1	0	0	1	1	0
-2/3 Vdc	0	0	1	0	1	1	0
-Vdc	1	0	0	0	1	1	0

3. SIMULATION RESULTS

Figure 8 depicts the proposed system, which was created using the MATLAB/Simulink application. Three PV systems with output DC voltages are used in this system (133.3 V, 266.6 V, and 400 V). The temperatures are a constant 25 °C. Irradiance is 1000 w/m[2]. PV-1 and PV-2 have a total output power of 2000 W, whereas PV-3 has a total output power of 3000 W. Figure 9 gives the (I-V) and (P-V) behavior of a selected PV panel. PV-1 and PV-2 systems are comprised of ten solar panels linked in parallel, with a 37.26 V output and a current of 53.7 A (10×5.37 A). Alternatively, PV-3, consists of 15 solar panels linked in parallel, with an output voltage of 37.26 V and a current of 80.55 A (15×5.37 A). Figure 10 shows the output voltage and current of three PV systems. Figure 11 is a circuit diagram of the boost converter implemented in MATLAB.

The boost converter duty cycle (*D*) is [29].

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{4}$$

Boost converter inductor and output capacitor behavior are given by (5) and (6), respectively, as

$$L_{min} = \frac{D\,(1-D)^2\,R}{2\,f} \tag{5}$$

$$C = \frac{D}{R\left(\frac{\Delta V_O}{V_O}\right)f} \tag{6}$$

where the $\left(\frac{\Delta V_O}{V_O}\right)$ output ripple voltage is 1%, *R* is output resistance, and *f* is the frequency. Boost converter characteristics are given in Table 2.

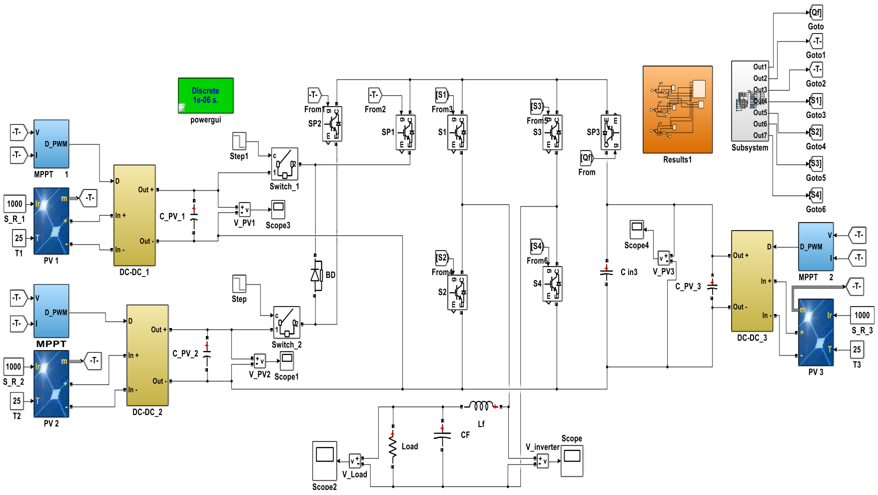
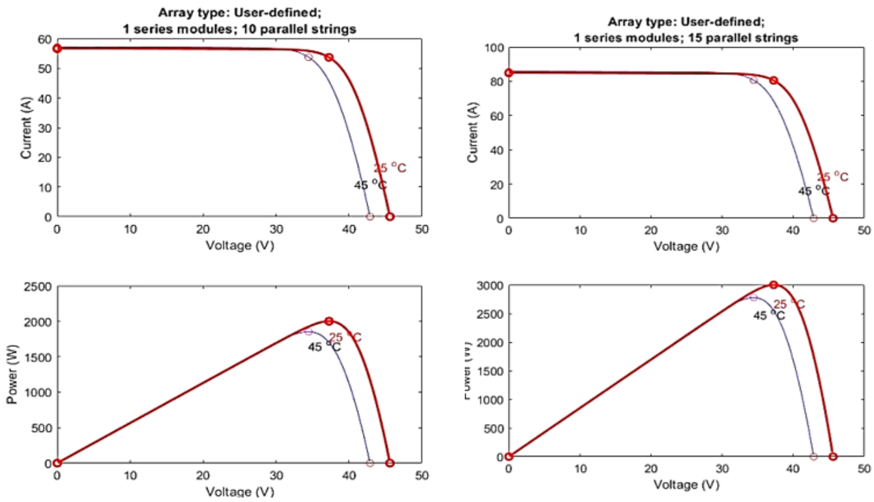
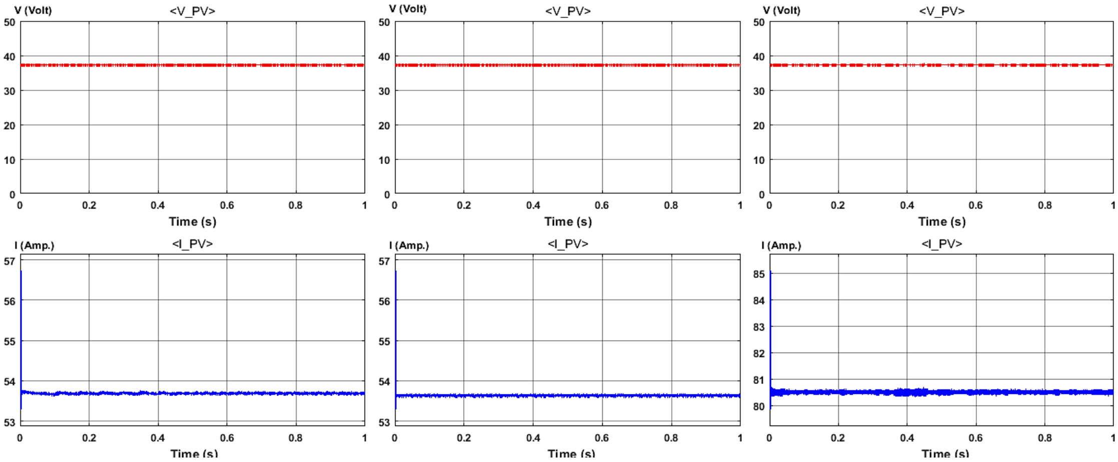


Figure 8. Proposed system implemented in the MATLAB program



(a) (b)

Figure 9. The (I-V) and (P-V) behavior of PV systems for (a) PV-1 and PV-2, (b) PV-2 and PV-33



(a) (b) (c)

Figure 10. Output voltage and current output of (a) PV systems, for (b) PV-1 and PV-2, and (c) PV-3

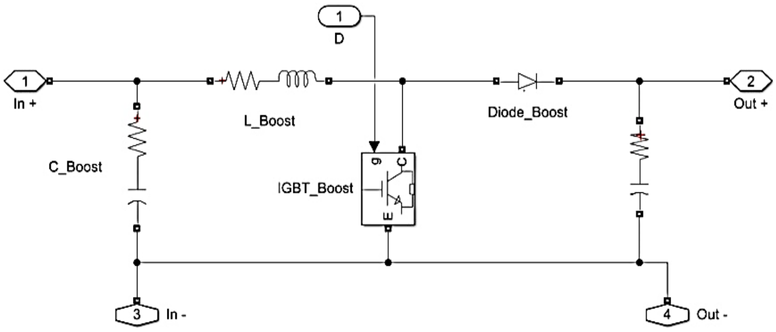


Figure 11. Boost converter design in MATLAB

The PV sub-modules (*i.e.*, PV-1, PV-2, and PV-3) are connected in series by switches (Sp1, Sp2, and S3). Switches pairs (S1, S4) and (S2, S3) operate alternately to achieve load voltage. These three PVs are linked to an MLI with seven switches. Here, the output voltage is exactly equivalent to the PV-3 voltage Vdc (400 V). PV-1 (1/3×400=133.3 V) and PV-2 (2/3×400= 266.6 V) are summed and are equivalent to the PV-3 output voltage. Figure 12 shows a seven-level voltage waveform with no LC filter. Figure 13 shows the same waveform with an LC filter.

THD is a total harmonic distortion measurement, calculated as a proportion of an overall aggregate harmonic component power to the fundamental frequency power [30]–[33]. THD is a calculation that determines system linearity and power quality. The total harmonic current distortion at a rated inverter output is much less than 5% of the fundamental frequency current, per IEEE standards. THD of the output voltage was 16.7% and 1.13%, respectively, with and without an LC filter. Proper design of LC filters reduces the harmonics. The THD with the LC filter from the MATLAB program is shown in Figure 14.

When a system has multiple PV systems, contingency analysis is necessary to ensure overall system reliability. For example, if PV-1 leaves service, the system shall continue to function, providing the designed output voltage. However, this voltage will drop from seven down to five levels while the THD subsequently rises. Figure 15 shows the output voltage in a case where the PV-1 is out of service at 0.5 s with no LC filter. The THD of a five-level inverter, which includes PV-2 and PV-3, rose by 3.51%. Figure 16 depicts a case when PV-2 is off-line with no LC filter. The THD of this five-level inverter, with PV-1 and PV-3, increases to 4.19%. When all PV systems are operational, seven-voltage levels are delivered at the output and the THD is 1.13%.

Table 2. Boost converter parameters

PV No.	Input voltage (V)	Output voltage (V)	Power (W)	Duty cycle	Inductor (mH)	Capacitor (uF)
1	37.26	133.3	2000	0.72	0.037.2	0.02
2	37.26	266.6	2000	0.86	0.748	0.6
3	37.26	400	3000	0.9	0.6	0.84

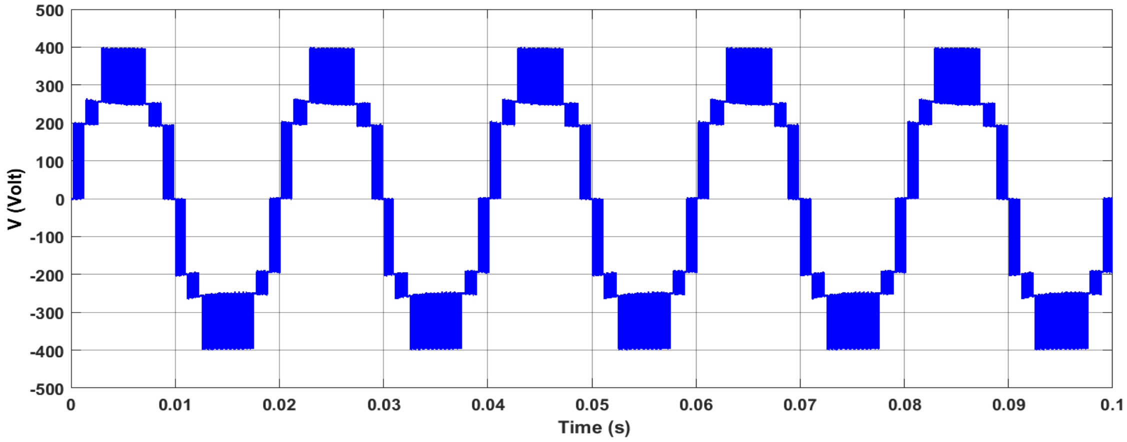


Figure 12. A waveform with seven levels and no LC filter

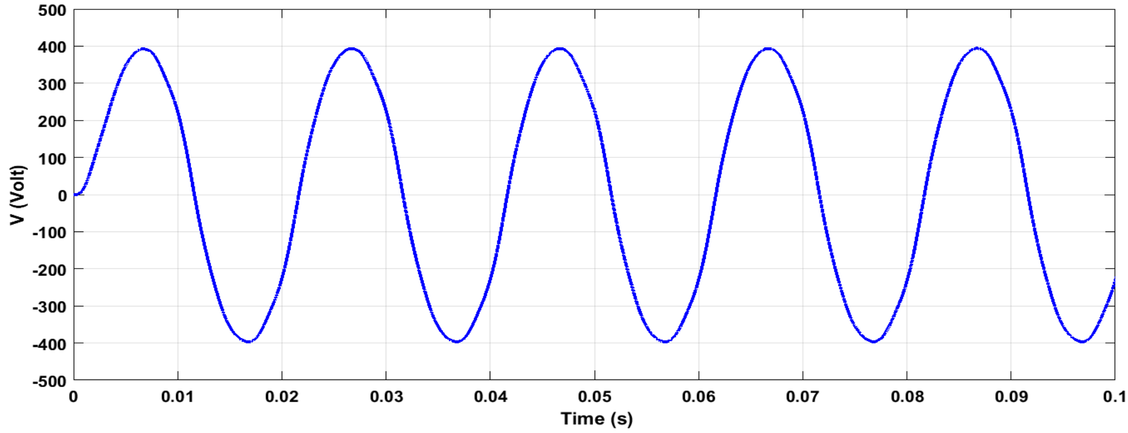


Figure 13. A waveform with seven levels with an LC filter

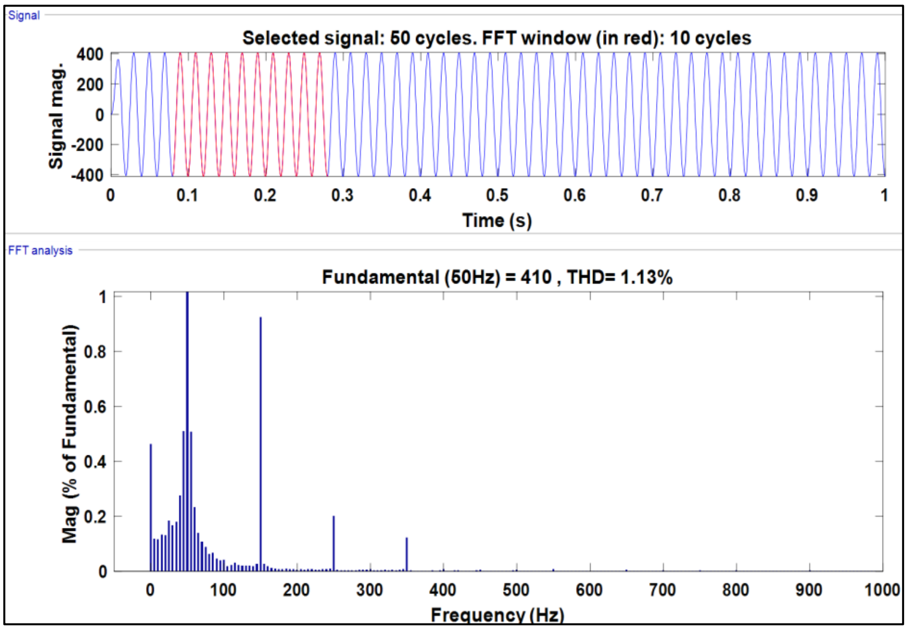


Figure 14. THD designed using the MATLAB program

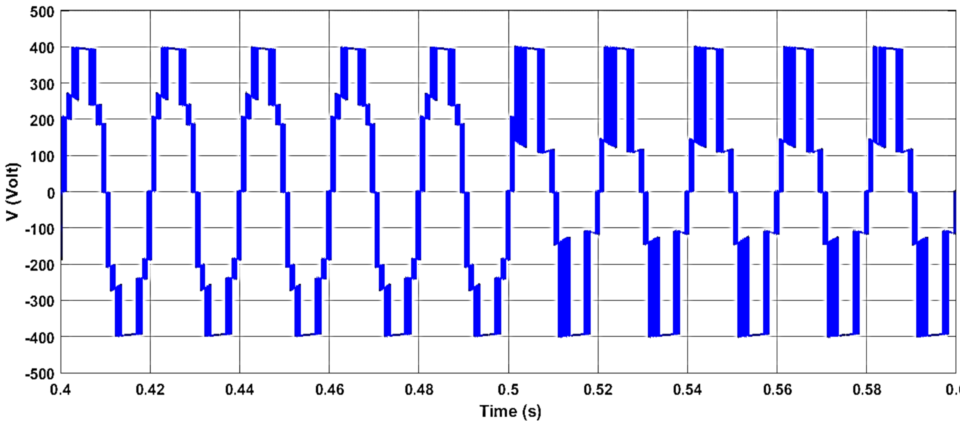


Figure 15. Transitioning from seven to five output voltage levels in the case of a PV-1 outage

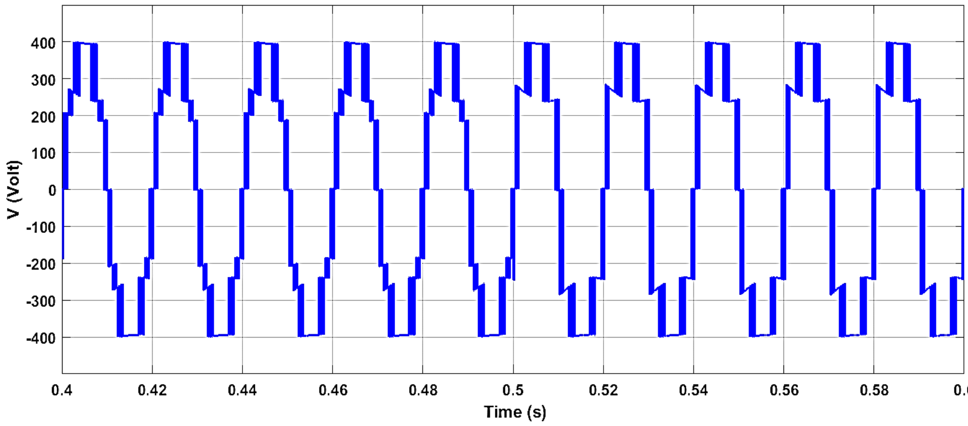


Figure 16. Transitioning from seven to five output voltage levels in the case of a PV-2 outage

4. COMPARISON WITH PREVIOUS WORKS

Table 3 lists the major differences among several previous works that have been mentioned in the introduction section. Comparisons are made of the number of AC voltage levels, as well as the capability to change the number of levels, the quantity of DC sources, DC source types, and the type of DC/DC converter. In this table, it can be seen that the proposed work aims to keep the RMS value of its output voltage at the same value when shifting from seven levels to five levels. The output voltage remains at its peak value, unchanged in the case when one of the DC supplies is unavailable to supply DC voltage. In the case of [13], the number of voltage levels is modified via changing the modulation index. However, this will lead to a decreased output RMS voltage. Also, in [16], an inverter is shown that can work at 9, 17, and 25 levels, but switching from nine levels to seventeen levels or to twenty five levels is not specified. Furthermore, in [16], the utilization of the MPPT technique with renewable energy sources is not done. Accordingly, such techniques can be used with promising non-traditional renewable energy systems, such as thermoelectric modules [34], [35].

Table 3 Comparison of earlier research and the current study

Ref. No.	Number of AC voltage Levels	Possibility to change number of levels	Number of DC sources	Type of DC sources	Type of DC/DC converter
[11]	3 (Full Bridge type)	No	2	Wind turbine & PV	Buck-Boost
[12]	5	No	1	PV	High step-up boost converter
[13]	7	Yes (through modulation index)	1	Not specified	Not specified
[14]	7	No	1	PV	Zeta converter
[15]	3 (Three-phase)	No	2	Wind turbine & PV	Not specified
[16]	25	Yes	3	Not specified	Not specified
Proposed work	7	Yes (with maintaining its peak value)	3	PV (Three different systems)	Boost converter

5. CONCLUSION

MATLAB/Simulink was utilized to develop and simulate an inverter with seven levels that was supplied by solar systems in this study. PV-1 and PV-2 with (Vdc/3) and (2 Vdc/3) output voltages are two of the three PV systems recommended, whereas PV-3 has a different voltage (+Vdc). The control circuit was constructed using a multicarrier PWM method. The voltage waveform with an LC filter has a THD of roughly 1.13%, which is within the IEEE519-2014 standard range. The output waveform voltage will be five levels if either PV-1 or PV-2 is out of operation for any reason and the THD will increase. However, the LC filter design will maintain THD so that it is always within acceptable limits. This design worked successfully, showing effective control and power circuits that were developed and recommended in the current study. In the future, the use of seven-level inverter will be considered in practice with thermoelectric systems that were developed by the current author. Connection of the system with the grid will be made with the design of a suitable voltage controller as well.

ACKNOWLEDGEMENTS

Funding from the Ministry of Science and Higher Education of the Russian Federation (Ural Federal University Program of Development within the Priority-2030 Program) is gratefully acknowledged: Grant Number FEUZ-2022-0031.

REFERENCES

[1] A. A. Bhatkar and A. P. Kinge, "A solar power generation system with a seven-level inverter," *International Research Journal of Engineering and Technology (IRJET)*, vol. 5, no. 4, pp. 3647–3651, 2018.
[2] T. M. Navinkumar, R. Aruljothi, M. Srinivasan, and A. A. Stonier, "Hybrid PV-wind system with power quality improvement using PV-DVR," *IOP Conference Series: Materials Science and Engineering*, vol. 1055, no. 1, p. 012145, 2021, doi: 10.1088/1757-899x/1055/1/012145.
[3] M. A. Qasim and V. I. Velkin, "Experimental investigation of power generation in a microgrid hybrid network," *Journal of Physics: Conference Series*, vol. 1706, no. 1, 2020, doi: 10.1088/1742-6596/1706/1/012065.
[4] A. I. M. Ali, M. A. Sayed, and A. A. S. Mohamed, "Seven-level inverter with reduced switches for pv system supporting home-grid and ev charger," *Energies*, vol. 14, no. 9, 2021, doi: 10.3390/en14092718.
[5] P. Balapriyan and K. Veeraragavan, "Design and analysis of 7-level inverter at different modulation indices with a closed loop control," *International Journal of Pure and Applied Mathematics*, vol. 119, no. 14, pp. 637–642, 2018.
[6] R. Al Badwawi, M. Abusara, and T. Mallick, "A review of hybrid solar PV and wind energy system," *Smart Science*, vol. 3, no. 3, pp. 127–138, 2015, doi: 10.1080/23080477.2015.11665647.
[7] M. Gnana Prakash, M. Balamurugan, and S. Umashankar, "A new multilevel inverter with reduced number of switches," *International Journal of Power Electronics and Drive Systems*, vol. 5, no. 1, pp. 63–70, 2014, doi: 10.22214/ijraset.2019.4005.
[8] A. Shrivastav, A. Sohail, R. Pandey, S. Sachan, and A. Professor, "Single phase seven level cascaded h-bridge multilevel inverter," *International Journal of Engineering Science and Computing*, vol. 7, no. 4, pp. 6477–6480, 2017, [Online]. Available: http://ijesc.org/.
[9] T. V. V. S. Lakshmi, N. George, S. Umashankar, and D. P. Kothari, "Cascaded seven level inverter with reduced number of switches using level shifting PWM technique," *Proceedings of 2013 International Conference on Power, Energy and Control, ICPEC 2013*, pp. 676–680, 2013, doi: 10.1109/ICPEC.2013.6527742.
[10] Y. Gopal, D. Birla, and M. Lalwani, "Reduced switches multilevel inverter integration with boost converters in photovoltaic system," *SN Applied Sciences*, vol. 2, no. 1, 2020, doi: 10.1007/s42452-019-1848-7.
[11] N. Archana and K. I. Anupamma, "Multi-input inverter for hybrid wind-photovoltaic standalone system," *Proceedings of the 2nd International Conference on Computing Methodologies and Communication, ICCMC 2018*, pp. 451–455, 2018, doi: 10.1109/ICCMC.2018.8488043.
[12] A. Nouaiti, A. Saad, A. Mesbahi, and M. Khafallah, "A new efficient topology of single-phase five-level inverter for PV system," *International Journal of Engineering and Technology Innovation*, vol. 8, no. 4, pp. 241–260, 2018.
[13] M. F. Mohammed, A. H. Ahmad, and A. T. Humod, "Design and simulation of a new seven levels inverter for renewable energy sources," *Journal of Engineering and Applied Sciences*, vol. 13, no. 16, pp. 6866–6872, 2018, doi: 10.3923/jeasci.2018.6866.6872.
[14] A. Azeem, M. K. Ansari, M. Tariq, A. Sarwar, and I. Ashraf, "Design and modeling of solar photovoltaic system using seven-level packed U-cell (PUC) multilevel inverter and zeta converter for off-grid application in India," *Electrica*, vol. 19, no. 2, pp. 101–112, 2019, doi: 10.26650/electrica.2019.18053.
[15] R. S. Jadhav and S. S. B. Patil, "Design and implementation of PV-wind battery hybrid system for off grid and on grid," *Proceedings of the 4th International Conference on Inventive Systems and Control, ICISC 2020*, pp. 612–618, 2020, doi: 10.1109/ICISC47916.2020.9171150.
[16] J. Sathik *et al.*, "A multilevel inverter topology using diode half-bridge circuit with reduced power component," *Energies*, vol. 14, no. 21, 2021, doi: 10.3390/en14217249.
[17] K. Tazi, F. M. Abbou, A. Bannour Chaka, and F. Abdi, "Modeling and simulation of a residential microgrid supplied with PV/batteries in connected/disconnected modes - Case of Morocco," *Journal of Renewable and Sustainable Energy*, vol. 9, no. 2, 2017, doi: 10.1063/1.4979355.
[18] M. A. Qasim and V. I. Velkin, "PWM effect on MPPT for hybrid PV solar and wind turbine generating systems at various loading conditions," *Periodicals of Engineering and Natural Sciences*, vol. 9, no. 2, pp. 581–592, 2021, doi: 10.21533/pen.v9i2.1840.
[19] Y. M. Chen, Y. C. Liu, S. C. Hung, and C. S. Cheng, "Multi-input inverter for grid-connected hybrid PV/wind power system," *IEEE Transactions on Power Electronics*, vol. 22, no. 3, pp. 1070–1077, 2007, doi: 10.1109/TPEL.2007.897117.
[20] S. Kumari and S. Y. Kumar, "A novel approach of controlling the solar PV integrated hybrid multilevel inverter," *Indonesian Journal of Electrical Engineering and Informatics*, vol. 6, no. 2, pp. 143–151, 2018, doi: 10.11591/ijeei.v6i2.354.
[21] G. M. Munde, M. A. Shelke, and F. H. Zameer, "A seven level inverter using a solar power generation system," *IJARIIE International Journal of Advance Research and Innovative Ideas in Education*, vol. 5, no. 1, pp. 652–657, 2019, doi: 16.0415/IJARIIE-9513.
[22] M. M. A. Awan, "Technical review of MPPT algorithms for solar photovoltaic system: SWOT analysis of MPPT," *Sir Syed*

University Research Journal of Engineering & Technology, vol. 12, no. 1, pp. 98–106, Jun. 2022, doi: 10.33317/ssurj.433.
[23] M. A. Qasim and V. I. Velkin, "Maximum power point tracking techniques for micro-grid hybrid wind and solar energy systems-A review," *International Journal on Energy Conversion*, vol. 8, no. 6, pp. 223–234, 2020, doi: 10.15866/irecon.v8i6.19502.
[24] M. M. A. Awan, M. Y. Javed, A. B. Asghar, and K. Ejsmont, "Performance optimization of a ten check MPPT algorithm for an off-grid solar photovoltaic system," *Energies*, vol. 15, no. 6, p. 2104, Mar. 2022, doi: 10.3390/en15062104.
[25] J. S. . and P. . Murugesan. G, "A New Multilevel Inverter Topology Using Less Number of Switches," *International Journal of Engineering Science and Technology(IJEST)*, vol. 3, no. 2, 2011.
[26] M. Austin Johnny and S. Joseph Jawhar, "Design and implementation of multilevel inverter for drive applications with minimum number of transistors," *Journal of Chemical and Pharmaceutical Sciences*, vol. 9, no. 1, pp. 378–382, 2016.
[27] R. J. Lakshmi, V. V. S. Bhavani, D. U. Anjali, K. Jagadeesh, and V. Vamsi, "A novel reduced-switch MLI topology for grid tied solar-PV systems," *International Journal of Advance Research and Innovative Ideas in Education (IJARIIE)*, vol. 7, no. 4, pp. 1182–1196, 2021.
[28] K. Mohan Raj, C. Ashwin Parthasarathy, S. S. Dash, and M. Arun Noyal Doss, "Performance comparison of seven level inverter and nine level inverter with minimum devices," *International Journal of Control Theory and Applications*, vol. 9, no. 15, pp. 7523–7536, 2016.
[29] A. Vijayakumar, A. Alexander Stonier, G. Peter, P. Kumaresan, and E. M. Reyes, "A modified seven-level inverter with inverted sine wave carrier for PWM control," *International Transactions on Electrical Energy Systems*, vol. 2022, 2022, doi: 10.1155/2022/7403079.
[30] K. Ranjith Kumar, M. Venkatesan, and R. Saravanan, "A hybrid control topology for cascaded multilevel inverter with hybrid renewable energy generation subsystem," *Solar Energy*, vol. 242, pp. 323–334, 2022, doi: 10.1016/j.solener.2022.07.021.
[31] S. B. Verma, G. H. Raisoni, and R. Rewatkar, "Comparison of grid connected 5-level and 7-level inverters," *International Journal of Electrical*, pp. 2320–2084, 2015.
[32] IEEE Standards Coordinating Committee 21 on Fuel Cells Photovoltaics Dispersed Generation and Energy Storage, "IEEE recommended practice for utility interface of photovoltaic (PV) Systems," vol. 2000, p. 32, 2000, doi: 10.1109/IEEESTD.2000.91304.
[33] P. Mishra and R. Maheshwari, "Design, Analysis, and Impacts of Sinusoidal LC Filter on Pulsewidth Modulated Inverter Fed-Induction Motor Drive," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 4, pp. 2678–2688, 2020, doi: 10.1109/TIE.2019.2913824.
[34] M. A. Qasim, V. I. Velkin, and S. E. Shcheklein, "The experimental investigation of a new panel design for thermoelectric power generation to maximize output power using solar radiation," *Energies*, vol. 15, no. 9, 2022, doi: 10.3390/en15093124.
[35] M. A. Qasim, V. I. Velkin, and S. E. Shcheklein, "Experimental and implementation of a 15 × 10 TEG array of a thermoelectric power generation system using two-pass flow of a tap water pipeline based on renewable energy," *Applied Sciences (Switzerland)*, vol. 12, no. 15, 2022, doi: 10.3390/app12157948.

BIOGRAPHIES OF AUTHORS

Mohammed A. Qasim Ph.D. Candidate at Ural Federal University, Department of Nuclear Power Plants and Renewable Energy Sources, Russia. Participated and member in IEEE Young Professionals. He has MSc degrees in Electromechanical Systems Engineering from University of Technology (2017), Baghdad, Iraq. earned his BSc in Electrical Engineering from University of Technology (2006), Baghdad, Iraq. Work in Ministry of Health since 2009 at Department of Projects and Engineering Services, Baghdad, Iraq. His research interests are thermoelectric systems, hydropower systems, Solar systems, electrical drives and control, and non-traditional renewable energy sources. He can be contacted at email: mkasim@urfu.ru.

Vladimir Ivanovich Velkin doctor of technical science, professor, at the Ural Federal University, Department of nuclear power plants and renewable energy sources, Russia; Deputy head of the scientific laboratory "Euro-Asian center for renewable energy and energy saving". He got a Ph.D. in 1996 from Ural Federation University. He has MSc degrees in 1982 from Ural Federation University. Received the degree of Doctor of Technical Sciences in 2018 from Peter the Great St. Petersburg Polytechnic University. Awards and scientific prizes: Winner of the national environmental award of the V. I. Vernadsky Foundation, (nomination "Energy of the future", 2009). His research interests are about renewable energy sources, nuclear power, and energy saving. He can be contacted at email: v.i.velkin@urfu.ru.

Mustafa Fawzi Mohammed is a Lecturer at the University of Information Technology and Communications, College of Business Informatics in Iraq. He got a Ph.D. in Electrical Engineering from the Dept. of Electrical Engineering, University of Technology, Iraq in 2019. Also, He has an M.E. in Power systems and Electrical drives from Thapar University, Patiala, India in 2012, and a B.Sc. in electrical engineering from College of Engineering, Al-Mustansirya University in 2007. His interests are about DC and AC power converters, electrical drives and control, and renewable energy systems. He can be contacted at email: mfmfzy@yahoo.com.

Alaa Ahmad Sammour is a PhD student, Department «Turbines and Engines, Department, Ural Federal University, Russia. He has a master's degree in Mechanical power engineering from Al-Baath University, Syria in 2019, and a B.Sc. in mechanical engineering from College of Engineering, Al-Baath University in 2015. His interests are about thermal modeling, computational simulation, power plants and renewable energy systems. He can be contacted at email: alpharam.eng@gmail.com.

Yang Du is a Ph.D student at Ural Federal University, Department of Nuclear Power Plants and Renewable Energy Sources, Russia. He got his bachelor's degree in Energy and Power Engineering in 2017 and master's degree in Hydraulic Engineering in 2020 at North China University of Water Resources and Electric Power in China. His research interests are in wind turbine optimization and renewable energy systems. He can be contacted at email: erica002@163.com.

Sajjad Abdul-Adheem Salih PhD student, Department of Nuclear Power Plants and Renewable Energy, Ural Federal University (UrFU), Russia. Master's degree in mechanical power engineering from Warsaw university of technology, Poland 2017, and a B.Sc. in mechanical engineering from College of Engineering, Al-Kufa University, Iraq 2007. Research about thermal power engineering, renewable energy technologies, simulation, and mathematical modelling. He can be contacted at email: sajjadsaleh85@gmail.com.

Baseem Abdulkareem Aljashaami PhD student, Department of nuclear power plants and renewable energy sources, Ural Federal University (UrFU), Russia. Master's degree in Building services, hydro and environmental engineering from Warsaw university of technology, Poland 2017, and a B.Sc. in Environmental engineering from college of engineering, Al-Mustansiriya University, Iraq 2003. Research about environment protection, renewable energy technologies, simulation, and mathematical modelling. He can be contacted at email: aljashamib@gmail.com.

Sharipov Parviz Gulmurodovich is a Ph.D student at Ural Federal University, Department of Nuclear Power Plants and Renewable Energy Sources, Russia. He has a master's degree (2019), and a B.Sc. (2017) in Electric Power and Electrical Engineering from the Ural Federal University, Russia. His research interests are about wind turbine optimization and renewable energy systems. He can be contacted at email: Parviz-93_tj@mail.ru.